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Interaction of Tillage and Nitrogen Rate Effect on Corn Response and N and P Uptakein a Corn-Soybean Rotation

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Introduction

Soil tillage has significant impact on the dynamics of soil moisture and nutrient in the soil system and the subsequent efficient extraction of soil water and uptake of nutrient by crop plants. Besides incorporating fertilizer and crop residue in the soil system, soil tillage improves soil aeration, the mineralization and availability of N and P and the subsequent uptake of both N and P by crop plants (Carter and Rennie, 1987; Dinnes et al., 2002; House et al., 1984; Varco et al., 1993). Contrary to conventional tillage systems, long-term no-tillage systems enhance greater mineralizable C and N pools in the soil system (Woods and Schuman, 1988; Doran, 1980). Therefore, the uptake of N by crop plants can be potentially changed with different tillage systems and their interactions with different N rates and N application timing. A significant interaction of tillage systems such as no-tillage (NT), conventional tillage (CT) or minimum tillage and N rate was observed on grain N uptake with increasing N removal as N rate increased (Halvorson et al., 2001). Therefore, an understanding of the effect of different tillage systems and their interactions with N rate from different N sources on the dynamics of available N and N uptake by crop plants at different growth stages is critical to the efficient management of N in crop production system. Similarly, plant P uptake is a function of soil moisture availability, the concentration of P in plant tissues, which decreases with plant age and water stress (Payne et al., 1995).

In a study, where N and P uptake by corn from two N sources of liquid swine manure and chemical N and P fertilizers were compared, it was found that N and P uptake and corn yield were similar for both N and P sources (Al-Kaisi and Waskom, 2002). The rising cost of chemical fertilizers makes liquid swine manure a viable alternative source of plant nutrients for corn production. Furthermore, the proximity of alternative sources of plant nutrients to corn production fields has the potential to reduce production cost and increase farmers' gross margin for corn production. Therefore, the objective of this research was to investigate the interaction effect of three tillage systems (NT, ST and CP) and four N rates of alternative sources of N on corn responses and N and P use efficiencies.

Materials and methods

This study was conducted on a 40-acre site at the Iowa State University Northeast Research and demonstration Farm near Nashua, IA from 2002 to 2004. The annual average of precipitation in the study location is 36 inch, with an average growing season rainfall of 28.04 inch. The soil at the site is Kenyon loam (fine loamy, mixed, mesic Typic hapludolls), which is nearly level to gently sloping. Prior to implementing the three tillage systems of no-tillage (NT), strip-tillage

(ST) and chisel plow (CP) for this study in 2002, the previous tillage system on this site was CP and field cultivated as primary and secondary tillage systems, respectively. The top 6 inch of the soil at the site was tested for initial values of total P, NO_3-N, organic matter and pH, which were 35, 163 and 11 ppm and 6.4%, respectively. The 40-acre site was divided into two 20-acre areas for corn and soybean rotations.

The focus of this study was to investigate corn response to three tillage systems and four N rates of the two N sources of liquid swine manure and anhydrous ammonia fertilizer in a corn-soybean rotation. In 2002, the 20-acre area to the east of the site was divided into two 10-acre areas north and south and planted with corn with the application of liquid swine manure and anhydrous ammonia fertilizer to the north and to the south areas, respectively. The experimental design for each corn experiment during each corn year was a randomized complete block with split-plots arranged in three replications. The three tillage systems of NT, ST and CP were assigned as the main plot treatments and the four N rates were randomly assigned as the subplot treatments. Each tillage treatment plot measured approximately 185 ft long and 69 ft wide with subplots for each N rate measuring approximately 185 ft long and 17 ft wide. Each tillage system was maintained at the same plot for the duration of the study. The western half of the site was planted to soybean in 2002. In 2003 the eastern half of the site was planted with soybeans following corn and the western half was planted with corn following soybeans with the same experimental design adopted for the 2002 corn experiment to the east half of the experimental site. In 2004, corn was planted after soybean crops to the east and soybeans were planted after corn to the west of the experimental site. The soybeans were planted in a 30.4 inch row spacing at a seeding rate of 168,000 plants acre^{-1} using the same tillage treatments for the previous corn experiment.

After harvest each year in the middle of November, CP and ST treatments were applied to both the corn and soybeans plots. Strip tillage was performed with a six-row ST unit equipped with mole knives and closing discs which created 8-inch deep tilled zones with approximately 3-inch berms.

During each year before field application of liquid swine manure, three manure samples were analyzed for total C, total N, total P, total K, ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) concentrations. Three-year averages of manure analysis were total C, 0.5%; total N, 55 lb N /1,000 gallons; total P, 40 lb P /1,000 gallons; total K 43 lb K /1,000 gallons; NH_4-N 0.5%; Nitrate 4.5 ppm. Each manure application rate was based on the average of three samples of total N concentrations. In 2002, 2003 and 2004, manure was injected 4 to 6 inches below the soil surface on 15 and 23 November, respectively at the rates of 0, 75, 150 and 225 lb acre^{-1} in each corn experiment using a Badger 5800 L manure applicator equipped with a modified injection knife to cause minimum soil disturbance in the same direction and location of previous rows in all tillage systems. There was no manure application after harvesting corn during the soybean season.

Anhydrous ammonia was also injected 4 to 6 inches below the soil surface in early April each year using a six-row pull-type anhydrous injection knife applicator. Corn was planted on the same manure and anhydrous ammonia bands in all tillage systems. In May of each year during planting, 25.9 lb P acre^{-1} ($NH_4H_2PO_4$) and 31.3 lb K acre^{-1} (KCL) was applied as starter fertilizer to the anhydrous ammonia plots at 2 inch deep and 2 inches from the center of the row.

In the spring of each year, the CP tillage treatment plots were field cultivated to control weeds and level the soil surface before planting corn. Dekalb 537 BT-corn was planted in all tillage treatments in early May of each year at a seeding rate of 33,600 plants acre^{-1} and at approximately 30 inch row spacing. Corn was planted over the disturbed zone of manure and anhydrous ammonia of all tillage treatments and simultaneously sprayed with 6.4EC Suprass at the rate of 20 gallons acre^{-1}. Corn grain was harvested at maturity using a combine with a scale monitor and grain yield was adjusted to 15% moisture.

Crop Measurements

Corn plant samples were collected at the sixth-leaf (V6), 12th-leaf (V12), tassel (VT) and at physiological maturity (R6) or black layer growth stages for each split plot to determine dry matter production, N and P uptake and recovery rate by corn plant. The plant sampling area per split plot was approximately 15 feet long, which was divided into three 5 feet segments of the sampling area. At each growth stage, a total of three corn plants were harvested from the 15 feet long sampling area, with one plant harvested from each 5 feet segment by cutting it at ground level, leaving two plants on both sides of the harvested plant. A separate area was maintained for grain harvest. Harvested plant samples were oven-dried at 140°F (60°C) for eight days to achieve a constant dry mass. Oven-dried plant samples were ground with a Wiley Mill Model 2 Carbon steel pulverizer and bagged in plastic-lined paper before analysis for the concentrations of total N and total P. Concentrations of total N and total P were determined by dry combustion using a LECO CHN-2000 CN analyzer and a microwave digestion and inductively coupled plasma (ICP) methods, respectively. Plant and corn grain N and P uptake were estimated as products of total plant dry matter or grain yield and their respective total N and total P concentrations. The recovery percentages of applied N and P by corn plant at different growth stages and grain were calculated with the following relationship:

N or P recovery % = [(N or P treatment uptake- control uptake)/ (Nor P) of applied N or P rate] x 100.

The three-year averages of applied P corresponding to the N rates of 0, 75, 150 and 225 lb acre^{-1} of manure were 0, 50, 100 and 159 lb P acre^{-1}, respectively. These values were used to estimate total P recovery from manure. The total P recovery from the anhydrous ammonia fertilizer experiment was estimated using the applied P rate of 26 lb P acre^{-1}.

Statistical analysis

Statistical analysis of the data was performed using a statistical analysis system package (SAS Institute, 2003). Data from each N source was analyzed separately using the GLM procedure for analysis of variance appropriate for a randomized complete block design with split-plot arrangement. Mean separations were performed by using the least significant difference ($P \leq 0.05$).

Results and discussion

Grain yield response to tillage and N rate

The main effect of tillage on grain yield was not significant with all N rates of both N sources (Table 1). Regardless of tillage system or N source, increasing the N rate above 75 lb N acre^{-1} had no significant effect in increasing grain yield. This is in agreement with N recommendations for corn after soybean in Iowa, where it ranges from 100-145 kg ha^{-1} (Blackmer et al., 1997). Also, these findings are in agreement with those by Licht and Al-Kaisi (2005a) for the same tillage systems. Generally, all tillage systems showed lower grain yields with zero N rate compared with high N rates regardless of N source. The corn response to different tillage systems and N management showed that type of tillage system has little effect on corn yield despite the initial differences in corn germination due to increase in soil temperature of 2.2-2.5°F degrees for ST and CP over NT in the top 2 inch (Licht and Al-Kaisi, 2005b). It was reported by others that the poor early season vegetative growth in the NT was due to low N availability (increased N immobilization, denitrification, and reduced organic N mineralization) and reduction in nutrient uptake by plants, which subsequently reduced crop yield compared with the ST and CP systems (Griffith et al., 1977; Ketchenson, 1980; Karlen et al., 1991; Mallarino et al., 1999). Regardless of tillage system, corn grain yield response depicted N poverty adjustment, where grain yield increased with additional 75 lb N acre^{-1} with no significant increase in yield above that N rate (Macy, 1936; Cerrato and Blackmer, 1990; Al-Kaisi and Waskom, 2002).

Table 1. Effect of tillage systems and N rates of two N sources on corn grain yield in 2002-2004.

		N rate lb acre^{-1}			
N Source	**Tillage Systems**†	**0**	**75**	**150**	**225**
		grain yield , bu acre^{-1}			
Manure	NT	99.8 Ab‡	138.6 Aa	156.5 Aa	159.4 Aa
	ST	104.3 Ab	144.5 Aa	155.0 Aa	160.9 Aa
	CP	119.2 Ab	159.4 Aa	163.9 Aa	168.4 Aa
Fertilizer	NT	96.9 Ab	150.5 Aa	157.9 Aa	156.5 Aa
	ST	128.1 Ab	150.5 Aa	153.5 Aa	153.5 Aa
	CP	117.7 Ab	149.0 Aa	156.5 Aa	157.9 Aa

†NT, no-tillage; ST, strip-tillage; CP, chisel plow.

‡ Means in column within each N rate with the same uppercase letter are not significantly different according to least square means for tillage and n rate interactions adjusted for multiple comparisons as P≤0.05. Means in rows within each tillage system with the same lowercase letter are not significantly different according to least square means for tillage and N rate interaction adjusted for multiple comparisons at P≤0.05.

Tillage and N rate effects on grain N and P uptake

Grain N and P uptake showed no significant differences between tillage systems for all N rates with manure (Table 2). In the manure source plots, regardless of tillage system, the grain N and P uptake had significantly increased with additional N application and the greatest N and P uptake was achieved with 225 lb N acre^{-1} of manure. The control treatment had the lowest grain N uptake (Table 2). The increase in N and P accumulation in grain can be attributed to greater yield response and N and P availability at the high manure application rate. The results showed that even with the increase of N application rate, which led to an increase in P application with manure source (manure application rate based on total N content), the increase in applied P had no effect on increasing grain P uptake or accumulation in the grain.

Table 2. Grain N and P uptake with different tillage systems and N rates of manure and fertilizer in 2002-2004.

N Source	Tillage† System	N rate lb acre^{-1} 0	75	150	225	N rate lb acre^{-1} 0	75	150	225
		total N uptake, lb acre^{-1}				total P uptake lb acre^{-1}			
Manure	NT	71.2Ad‡	90.9Ac	109.0Ab	122.6Aa	10.4Ab	15.2Ab	15.3Ab	19.2Aa
	ST	73.7Ab	100.3Ab	112.5Aa	120.0Aa	11.7Aa	16.7Aa	15.2Aab	17.8Aa
	CP	73.9Ab	101.6Ab	103.2Ab	127.7Aa	10.4Aa	17.6Aa	16.0Aa	17.6Aa
Fertilizer	NT	68.4Bc	109.3Aa	129.0Aa	127.3Aa	9.1Ab	14.6Aa	14.9Aa	14.8Aa
	ST	88.8Ab	120.6Aa	116.5Ba	124.2Aa	9.8Ab	12.6Aab	14.3Aa	13.1Aab
	CP	77.6Bb	104.1Ba	112.5Ba	126.0Ba	10.7Aa	14.9Aa	13.8Aab	14.2Aab

†NT, no-tillage; ST, strip-tillage; CP, chisel plow.

‡ Means in column within each N rate with the same uppercase letter are not significantly different according to least square means for tillage and n rate interactions adjusted for multiple comparisons as P≤0.05. Means in rows within each tillage system with the same lowercase letter are not significantly different according to least square means for tillage and N rate interaction adjusted for multiple comparisons at P≤0.05.

In the fertilizer source plots, ST grain N uptake was greater compared with NT and CP, especially at 0 and 75 lb N acre^{-1} (Table 2). However, grain P uptake with different tillage systems was not significantly different regardless of N rate. The only difference in P uptake with fertilizer source was observed between 0 and other N rates across all tillage systems. The greater grain N uptake with the fertilizer source in ST compared with the NT can be attributed to better soil conditions associated with the ST system, where early spring increase in soil temperature in poorly drained soils improved corn germination, compared with NT as documented by Licht and Al-Kaisi (2005b).

Tillage and N rate effects on grain recovery of applied N and P

The grain recovery of applied N from both N sources was generally greater with 75 lb N acre^{-1} rate compared with the other two higher application N rates in all tillage systems (Table 3). However, it was observed that both ST and CP improved grain N recovery, especially with manure source at the 75 lb N acre^{-1} rate. The increase in N application rate beyond 75 lb N acre^{-1} did not increase grain-N recovery with all tillage systems. It was observed that grain N recovery of applied N fertilizer with NT was greater compared to ST and CP at 75 lb N acre^{-1} and 150 N lb acre^{-1} rates. These finding are consistent with those by Al-Kaisi and Waskom, 2002. It appears that the increase in N rate beyond 75 lb N acre^{-1} did not contribute significantly to recovering applied N with both N sources regardless of tillage system. The grain P recovery was significantly greater with CP treatment compared with the NT or ST with manure at 75 lb N acre^{-1} rate. The increased amount of applied P with manure did not lead to greater grain P recovery, where manure N rate application was based on total N content. However, NT grain P recovery in the fertilizer source plots was significantly greater than that with ST or CP at all N rates (Table 3). These findings are in agreement with those described by Al-Kaisi and Licht (2004) for the same tillage systems.

Table 3. Grain N and P recovery with various tillage systems and N rates of manure and fertilizer in 2002-2004

		N rate lb acre^{-1}							
N Source	**Tillage† System**	**0**	**75**	**150**	**225**	**0**	**75**	**150**	**225**
		------------ N recovery %------------				------------ P recovery % ------------			
Manure	NT	-	26.0Ba‡	25.0Aa	23.1Aa	-	9.5Ba	4.7Ab	5.5Ab
	ST	-	35.1Aa	25.6Ab	20.8Ab	-	9.9Ba	3.4Ab	3.8Ab
	CP	-	36.6Aa	19.4Ac	24.3Ab	-	14.3Aa	5.5Ab	4.5Ab
Fertilizer	NT	-	53.9Aa	40.0Ab	26.4Ac	-	21.4Aa	22.2Aa	22.4Aa
	ST	-	41.9Ba	18.3Bb	15.9Ab	-	10.6Bb	17.3Aa	12.9Bab
	CP	-	34.9Ba	23.0Bb	17.7Ac	-	16.1ABa	11.8Bb	13.3Bb

†NT, no-tillage; ST, strip-tillage; CP, chisel plow.

‡ Means in column within each N rate with the same uppercase letter are not significantly different according to least square means for tillage and n rate interactions adjusted for multiple comparisons as P≤0.05. Means in rows within each tillage system with the same lowercase letter are not significantly different according to least square means for tillage and N rate interaction adjusted for multiple comparisons at P≤0.05.

Effects of tillage, N rate, and season interactions on grain N and P uptake and recovery

Interaction effects of tillage × N rate, tillage × year, and N rate × year on grain N and P uptake were frequently observed with both N sources, although inconsistent (Table 4). The only significant interaction between tillage and N rate was observed with grain N uptake for the fertilizer source. The tillage x year interaction had significant effect on grain N and P uptake of manure source and on grain N uptake with fertilizer source. However, the N rate x year interaction had a significant effect on grain N and P uptake with manure and fertilizer sources, respectively (Table 4). Even though these interactions are inconsistent with both N sources, they reflect the seasonal variability effect on grain-N and P uptake with different tillage systems. Generally, there was insignificant three-way interaction of tillage x N rate x year effect on grain N and P uptake with both N sources. These finding are consistent with observations described by Dharmakeerthi et al., 2006, where N fertilizer level and tillage interaction effect was not significant during any growth stage.

Table 4. Effects of the interaction of tillage, N rate and year on N and P uptake by corn plant and grain with manure and N sources.

		P>F			
		Manure		Fertilizer	
Growth stage†	Source	N uptake	P uptake	N uptake	P uptake
V6	Tillage x N rate	0.001	0.034	0.005	0.001
	Tillage x year	0.008	0.074	0.019	0.002
	N rate x year	<0.0001	0.006	<0.0001	<0.0001
	Tillage x N rate x year	0.214	0.257	0.073	0.0468
V12	Tillage x N rate	0.077	0.158	0.329	0.926
	Tillage x year	0.496	0.047	0.113	0.556
	N rate x year	<0.0001	0.350	0.029	0.196
	Tillage x N rate x year	0.365	0.264	0.289	0.175
VT	Tillage x N rate	0.887	0.293	0.016	0.973
	Tillage x year	0.559	0.004	0.216	0.741
	N rate x year	<0.0001	0.026	0.003	0.746
	Tillage x N rate x year	0.332	0.530	0.576	0.985
R6	Tillage x N rate	<0.0001	0.001	0.535	0.015
	Tillage x year	0.956	0.043	0.973	0.320
	N rate x year	0.002	0.002	0.005	0.101
	Tillage x N rate x year	0.225	0.020	0.098	0.002
Grain	Tillage x N rate	0.251	0.813	0.004	0.830
	Tillage x year	<0.0001	0.049	0.006	0.715
	N rate x year	0.110	0.008	0.021	0.927
	Tillage x N rate x year	0.149	0.265	0.047	0.978

†V6, sixth-leaf stage of corn; V12, 12th-leaf stage of corn; VT, tassel stage of corn; R6, physiological maturity stage of corn. Significant level ($P \leq 0.05$).

The grain N and P recovery interactions are summarized in Table 5. Tillage x N rate, tillage x year, N rate x year, and tillage x N rate x year interactions had no significant effect on grain N and P recovery with both N sources, except in a few cases. It appears that tillage x year had significant effect on grain P and N and P recoveries with manure and fertilizer sources, respectively (Table 5). This can be attributed to tillage effect on both N and P availability and N and P uptake. It was found that banded P (deep or shallow) increased early corn growth and P uptake more than broadcast placement with NT (Mallarino et al., 1999).

Table 5. Effects of the interaction of tillage, N rate and year on applied N and P recovery by corn plant and grain with manure and N sources.

		P>F			
		Manure		Fertilizer	
Growth stage†	Source	N uptake	P uptake	N uptake	P uptake
V6	Tillage x N rate	0.098	0.324	0.0381	0.001
	Tillage x year	0.786	0.102	0.0104	0.154
	N rate x year	<0.0001	0.031	0.0001	<0.0001
	Tillage x N rate x year	0.491	0.181	0.0250	0.012
V12	Tillage x N rate	0.007	0.147	0.1551	0.822
	Tillage x year	0.235	0.063	0.2379	0.058
	N rate x year	0.010	0.765	0.3857	0.051
	Tillage x N rate x year	0.075	0.078	0.5653	0.027
VT	Tillage x N rate	0.928	0.626	0.5054	0.969
	Tillage x year	0.894	0.567	0.4870	0.314
	N rate x year	<0.0001	0.179	0.0903	0.723
	Tillage x N rate x year	0.267	0.352	0.7687	0.982
R6	Tillage x N rate	<0.0001	0.273	0.2602	0.002
	Tillage x year	0.001	0.572	0.5690	0.825
	N rate x year	<0.0001	0.001	0.0007	0.023
	Tillage x N rate x year	0.152	0.074	0.060	<0.0001
Grain	Tillage x N rate	0.272	0.642	0.142	0.505
	Tillage x year	0.769	0.047	0.091	0.032
	N rate x year	0.197	0.240	0.001	0.726
	Tillage x N rate x year	0.493	0.018	0.642	0.793

†V6, sixth-leaf stage of corn; V12, 12th-leaf stage of corn; VT, tassel stage of corn; R6, physiological maturity stage of corn. Total N determined at R6 for plant biomass only without grain. Significant level ($P \leq 0.05$).

Tillage and N rate effects on plant-N and P uptake at different growth stages

Generally, plant N uptake was significantly greater with CP system compared with NT at 75 lb N acre^{-1} and 150 lb N acre^{-1} N rates of manure source at V6 to R6 growth stages (Table 6). The observed tillage effect on the plant N uptake may be attributed to the differences in crop growth rates because N uptake is controlled by N availability and crop growth rate (Devienne-Barret et al., 2000). The plant N uptake at the 225 lb N acre^{-1} N rate was inconsistent during all growth stages. The differences in plant N uptake between N rates within each tillage system showed generally greater plant N uptake with the increase in N rate up to 150 lb N acre^{-1} for manure source. These findings are in agreement with those by Dharmakeerthi et al., 2006, where plants growing in treatments with higher N application took up significantly more N than 0 N treatments at all growth stages.

Table 6. Corn Plant N and P uptake with three tillage systems and four N rates of manure at four growth stages in 2002-2004.

		N rate lb acre^{-1}				**N rate lb acre^{-1}**			
Growth Stage†	**Tillage System‡**	**0**	**75**	**150**	**225**	**0**	**75**	**150**	**225**
		------------- N uptake, lb acre^{-1}-------------				----------- P uptake lb acre^{-1}---------			
V6	NT	4.3Ad§	11.1ABb	7.9Bc	14.7ABa	0.5Ac	0.9Ab	1.0Bb	1.4Aa
	ST	4.7Ac	9.6Bb	9.5Bb	16.7Aa	0.5Ab	0.8Ab	1.3Aa	1.2Aa
	CP	6.7Ab	12.7Aa	13.8Aa	13.6Ba	0.6Ac	1.1Ab	1.5Aa	1.3Aa
V12	NT	47.5Ab	64.6Bb	104.4Ba	87.2Aa	6.3Ac	8.1Bbc	9.0Bab	10.6Aa
	ST	49.6Ab	97.5Aa	111.6Aa	105.7Aa	6.5Ab	9.3ABa	10.9Aa	11.4Aa
	CP	61.9Ac	109.3Aa	113.3Aa	92.2Ab	6.8Ab	10.6Aa	11.3Aa	9.8Aa
VT	NT	73.0Bc	123.1Bb	149.6Ca	108.7bb	11.2Ab	15.0Aa	15.5Ba	16.2Aa
	ST	68.6Bc	135.2Bb	168.3Ba	129.9Ab	10.8Ab	16.0Aa	17.9ABa	15.4Aa
	CP	90.9Ad	153.4Ab	189.0Aa	125.9Ac	12.9Ac	17.8Ab	20.6Aa	15.9Ab
R6	NT	62.4ABb	93.8Ba	99.1Ba	97.2ABa	10.3Ab	20.9Ba	18.0Ba	21.2Aa
	ST	68.8Ab	98.8Ba	96.4Ba	104.7Aa	12.9Ac	24.4Aa	17.6Bb	20.3Ab
	CP	47.3Bb	111.2Aa	123.8Aa	83.5Bc	12.3Ac	24.6Aa	22.0Aa	16.7Bb

†V6, sixth-leaf stage of corn; V12, 12th-leaf stage of corn; VT, tassel stage of corn; R6, physiological maturity stage of corn.

‡NT, no-tillage; ST, strip-tillage; CP, chisel plow.

§$P \leq 0.05$. Means in rows within each tillage system with the same lowercase letter are not significantly different according to least square means for tillage and N rate interaction adjusted for multiple comparisons at $P \leq 0.05$.

The plant P uptake was generally not significantly different for all tillage systems at 0 kg N ha^{-1} rate during all growth stages with manure source (Table 6). However, the increase in application of N rate showed inconsistent differences between tillage systems for plant P uptake with some advantages for CP and ST systems over NT. The increase in manure application rate that led to a greater amount of P application did not cause significant differences in plant P uptake between tillage treatments. These findings are not surprisingly unexpected due to high soil-P test of the site.

In the fertilizer source plots, the tillage effect on plant N uptake with different N rates was highly variable during all growth stages (Table 7). At the V6 to R6 growth stages, the difference in plant N uptake was only significant between 0 and high N rates across all tillage systems. It was noticeable at the VT growth stage that a maximum N accumulation was reached and greater plant N uptake was observed at all fertilizer N rates for the CP tillage system, except at the 225 lb N acre^{-1}(Table 7).

Table 7. Corn Plant N and P uptake with three tillage systems and four N rates of fertilizer at four growth stages in 2002-2004.

		N rate lb acre^{-1}				N rate lb acre^{-1}			
Growth Stage†	Tillage System‡	0	75	150	225	0	75	150	225
		----------- N uptake, lb acre^{-1}----------				---------- P uptake lb acre^{-1}----------			
V6	NT	6.3Bb§	11.4Ba	10.9Aa	10.0Ba	0.4Ac	0.9Aa	0.7Ab	0.9Ba
	ST	6.9ABb	10.5Ba	10.4Aa	9.3Ba	0.4Ab	0.8Ba	0.7Aa	0.7Ca
	CP	8.5Ac	14.7Aa	11.4Ab	15.6Aa	0.5Ad	1.0Ab	0.8Ac	1.2Aa
V12	NT	46.6Ab	63.2Bb	98.9Aa	73.9Aa	4.6Ab	6.6Aa	6.8Aa	6.9Aa
	ST	58.1Ac	103.5Aba	116.5Aa	88.9Ab	4.7Ab	7.4Aa	8.4Aa	7.1Aa
	CP	63.0Ab	99.4Aa	102.0Aa	95.4Aa	5.6Ab	8.1Aa	8.6Aa	8.1Aa
VT	NT	78.2Bc	131.5Bb	165.0Ba	135.6Bb	8.7Bb	13.1Ba	13.0Ba	12.2Ba
	ST	66.1Bc	133.5Bb	154.5Bb	181.1Aa	9.2Bb	13.2Ba	13.6Ba	13.3Ba
	CP	104.6Ac	170.9Aba	190.8Aa	142.8Bb	11.6Ab	15.6Aa	17.2Aa	16.4Aa
R6	NT	47.2Ac	83.9Aab	101.3Ba	69.4Ab	5.4Ab	14.1Aa	11.5ABa	10.9Aa
	ST	37.8Ab	81.4Aa	86.4Ba	80.3Aa	5.2Ab	12.4Aa	7.4Bb	12.1Aa
	CP	47.5Ac	70.9Ab	111.1Aa	66.3Ab	4.3Ab	7.9Bb	14.6Aa	8.2Ab

†V6, sixth-leaf stage of corn; V12, 12th-leaf stage of corn; VT, tassel stage of corn; R6, physiological maturity stage of corn.

‡NT, no-tillage; ST, strip-tillage; CP, chisel plow.

§ Means in column within each N rate with the same uppercase letter are not significantly different according to least square means for tillage and n rate interactions adjusted for multiple comparisons as P≤0.05. Means in rows within each tillage system with the same lowercase letter are not significantly different according to least square means for tillage and N rate interaction adjusted for multiple comparisons at P≤0.05.

Generally, at the V6 to R6 growth stages, plant P uptake was not significantly different between 0 and high N rates of fertilizer source regardless of the tillage system (Table 7). Plant P uptake exhibited a similar pattern, where corn plant P uptake in the CP tillage system was greater at the VT growth stage than ST and NT for all N rates (Table 7). This may be attributed to the effect of tillage on N and P availability by increasing soil temperature, increasing crop growth rate early in the season, and increased availability of N and P (Devienne-Barret et al., 2000; Licht and Al-Kaisi, 2005b). Mallarino et al. (1999) found also that deep banded P (deep or shallow) increased early corn growth and P uptake more than broadcast placement with NT.

The plant N uptake at the V12 growth stage across all tillage systems was calculated as a percentage of total N uptake (grain+plant) (Tables 2 and 6) for manure source was 42, 41, 50, and 43%, for 0, 75, 150, and 225 lb N acre^{-1} N rates, respectively. Similarly, N uptake was calculated as a percentage of total N uptake (grain + plant) (Tables 2 and 7) at the V12 growth stage across all tillage systems with fertilizer source was 41, 44, 47, and 41% for 0, 75, 150 and 225 lb N acre^{-1}, respectively. The P uptake at the V12 growth stage across all tillage systems as a percentage of total P uptake (grain + plant) was 37, 42, 41, and 36% and 35, 33, 36, and 33% for the above N rates of manure and fertilizer N sources, respectively.

Tillage and N rate effects on plant recovery of applied N and P at different growth stages

The recovery of applied N and P from both manure and fertilizer sources by corn plant progressively increased with corn growth through VT growth stage (Tables 8 and 9). However, the greatest N recovery was observed at the 75 lb N acre^{-1} N rate across all tillage systems with both N sources at the VT growth stage (Tables 8 and 9). Generally, increased N rate resulted in a decrease in plant N and P recovery with all tillage systems.

Table 8. Corn Plant N and P recovery with various tillage systems and N rates of manure at four growth stages in 2002-2004.

		N rate lb acre^{-1}				N rate lb acre^{-1}			
Growth Stage†	**Tillage System‡**	**0**	**75**	**150**	**225**	**0**	**75**	**150**	**225**
		N recovery %				P recovery %			
V6	NT	-	8.9Aa§	2.3Ab	4.7Ab	-	0.7ABa	0.4Bb	0.5Aab
	ST	-	6.4Ba	3.1Ab	5.3Aa	-	0.5Ba	0.6ABa	0.4Aa
	CP	-	7.9Aa	4.7Ab	3.1Ab	-	0.9Aa	0.9Aa	0.5Ab
V12	NT	-	22.4Bb	37.4Aa	17.7ABb	-	3.8Ba	2.8Aa	2.8Aa
	ST	-	63.2Aa	41.3Ab	25.1Ac	-	5.5ABa	4.3Aa	3.1Ab
	CP	-	62.5Aa	33.9Ab	15.7Bc	-	7.5Aa	4.4Ab	1.9Ac
VT	NT	-	66.0Ba	50.4Aa	16.0Bb	-	7.4Aa	4.3Ab	3.1Ab
	ST	-	87.7Aa	65.7Ab	27.5Ac	-	9.7aa	6.9Ab	2.9Ac
	CP	-	82.4Aa	64.7Ab	15.7Bc	-	9.8Aa	7.7Ab	1.9Ac
R6	NT	-	41.3Ba	24.2Bb	15.6Ac	-	21.3Aa	7.7Ab	6.9Ab
	ST	-	39.6Ba	18.7Bb	16.1Ab	-	23.1aa	4.7Ab	4.7Ab
	CP	-	84.1Aa	50.3Ab	16.2Ac	-	24.5Aa	9.6Ab	2.8Ac

†V6, sixth-leaf stage of corn; V12, 12th-leaf stage of corn; VT, tassel stage of corn; R6, physiological maturity stage of corn.

‡NT, no-tillage; ST, strip-tillage; CP, chisel plow.

§ Means in column within each N rate with the same uppercase letter are not significantly different according to least square means for tillage and n rate interactions adjusted for multiple comparisons as P≤0.05. Means in rows within each tillage system with the same lowercase letter are not significantly different according to least square means for tillage and N rate interaction adjusted for multiple comparisons at P≤0.05.

Table 9. Corn Plant N and P recovery with various tillage systems and N rates of fertilizer at four growth stages in 2002-2004.

		N rate lb acre^{-1}				N rate lb acre^{-1}			
Growth Stage†	Tillage System‡	0	75	150	225	0	75	150	225
		N recovery %				P recovery %			
V6	NT	-	6.7Aa§	3.0Ab	1.6Bc	-	1.8Aa	0.8Ab	1.6Ba
	ST	-	4.9Ba	2.3Ab	1.1Bb	-	1.2Ba	1.0Aa	1.0Ca
	CP	-	8.2Aa	1.9Ab	3.2Ab	-	1.5ABb	0.9Ac	2.2Aa
V12	NT	-	21.9Bb	34.5Aa	12.2Ac	-	7.7Aa	8.3Ba	8.7Aa
	ST	-	59.8Aa	38.5Ab	13.8Ac	-	10.3Ab	14.2Aa	8.9Ab
	CP	-	48.0Aa	25.7Ab	14.5Ac	-	9.8Aa	11.5Aa	9.7Aa
VT	NT	-	70.2Aa	57.1Ab	25.7Bc	-	17.3Aa	16.9Aa	13.7Ab
	ST	-	88.8Aa	58.2Ab	51.5Ab	-	15.4Aa	17.0Aa	15.8Aa
	CP	-	87.3Aa	56.8Ab	17.1Bc	-	15.5Ab	21.5Aa	18.4Aab
R6	NT	-	48.3Aa	35.6Ab	9.9Bc	-	33.8Aa	23.5Bb	21.1ABb
	ST	-	57.4Aa	32.1Ab	19.0Ac	-	27.9Aa	8.4Cb	26.6Aa
	CP	-	30.8Bb	41.9Aa	8.4Bc	-	13.7Bb	39.5Aa	14.9Bb

†V6, sixth-leaf stage of corn; V12, 12th-leaf stage of corn; VT, tassel stage of corn; R6, physiological maturity stage of corn.

‡NT, no-tillage; ST, strip-tillage; CP, chisel plow.

§ Means in column within each N rate with the same uppercase letter are not significantly different according to least square means for tillage and n rate interactions adjusted for multiple comparisons as P≤0.05. Means in rows within each tillage system with the same lowercase letter are not significantly different according to least square means for tillage and N rate interaction adjusted for multiple comparisons at P≤0.05.

The low recovery of P by the corn plant at all growth stages with both manure and fertilizer sources may be attributed to the lack of corn response to any additional P application due to high soil P test (> 35 ppm). It was found that P absorption by soil particles in surface layers in NT are often reduced compared with CP, where soil surface disturbance helped incorporate P and increase opportunities for soil-P reaction (Edwards et al., 1988; Guertal et al., 1991). It was always believed that NT might have a disadvantage in nutrient availability and the need for additional N and P applications compared to conventional tillage systems. However, these findings showed the limited effect of increased N or P applications have on increasing the utilization or recovery of these two nutrients by corn grown in all tillage systems.

Effects of tillage, N rate, and season interactions on plant N and P uptake and recovery

The interactions of tillage × N rate, tillage × year, and N rate × year had significant effect on plant N and P uptake during early growth stage (V6), but tillage × N rate × year had only significant effect on plant P uptake with fertilizer source (Table 4). Changes in soil conditions because of different tillage along with seasonal variability may contribute to change in N and P availability early in the growing season. Thus, significant tillage effect on plant N uptake could often be observed during the early parts of the growing season (Dharmakeerthi et al., 2006). The interaction effect of tillage x N rate, tillage x year, and N rate x year after the V6 growth stage on plant N and P uptake was inconsistent with both N sources. These interactions effects on plant N and P uptake were insignificant particularly late in the season, where tillage systems have very limited effect on plant N or P uptake. These observations are similar to those by Dharmakeerthi et al., 2006, where plant N uptake between V6 growth stage and silking is not significantly affected by tillage system. The few cases of increase in plant N and P uptake that were observed with CP tillage system with both N sources is highly related to soil temperature increase and enhanced early plant growth compared with NT (data not presented). The cool soil conditions associated with the NT system tend to reduce early plant growth and nutrient uptake (Licht and Al-Kaisi, 2005b). It was observed that at the R6 all interactions of tillage, N rate, and year in affecting plant N and P uptake were inconsistent with both N sources. Tillage x N rate, and N rate x year were significant at the R6 growth stage in affecting plant N and P uptake with manure source, and only N rate x year was significant in affecting plant N uptake with fertilizer source (Table 4). The three-way interaction of tillage, N rate, and year had a significant effect on plant P uptake at the V6 growth stage with fertilizer N source and at the R6 growth stage with both N sources (Table 4). These interactions indicate that N rate and seasonal variability have more effect on plant N and P uptake later in the growing season than tillage system. Dharmakeerthi et al., 2006, found that N uptake was affected by fertilizer N management during the V6 growth stage to maturity.

The only significant interaction in affecting plant N and P recovery of applied N and P was tillage x N rate at the V6 growth stage with both N sources (manure and fertilizer). It was observed that 31, 13, and 69% of the two-way interactions of tillage × N rate, tillage × year, and N rate × year, respectively, have a significant effect ($P < 0.05$) on N and P recovery from V6 to R6 growth stages (Table 5). However, only 25% of the three-way interaction effects of tillage × N rate × year on N and P recovery were significant ($P < 0.05$) from V6 to R6 growth stages (Table 5).

Conclusions

The findings of this research showed regardless of N source and tillage system, corn yield did not increase significantly with increasing N rate application above 75 lb N acre^{-1}. The effect of tillage system on grain-N uptake at different N rates with both N sources was generally insignificant, except with fertilizer source, where ST had improved N uptake compared with NT and CP for the 0 and 75 lb N acre^{-1} rates. The interaction effect of tillage × N rate on grain N and P uptake was inconsistent, except for N uptake with fertilizer source. Across all tillage systems and N rates, plant N and P uptake percentages at the V12 growth stage represent 44% and 39% of total plant + grain N uptake, respectively with manure source, and 43% and 34%, respectively with fertilizer source.

The tillage × N rate effect on plant N and P recovery was only significant at V6 growth stage with both N sources. However, most dominant interaction effect on plant N and P uptake and recovery was N rate x year from V6 to R6 growth stages. This significant interaction effect on plant N and P uptake and recovery was consistent with both N sources at the V6 and R6 growth stages. This indicates that seasonal variability has more effect on N availability than the type of tillage system. The three-way interaction effect of tillage x N rate x year on plant N and P recovery was generally insignificant, and only 25% of this interaction was significant from the V6 to R6 growth stages.

The findings suggest that both N sources have a similar effect on yield and N and P uptake regardless of tillage type. Additional N application from both N sources did not increase N uptake or yield for one particular tillage system over another. The findings of this study also indicate that the most effect a tillage system can have on plant N and P uptake was early in the growing season with both N sources, and it had a limited effect on plant N and P uptake later in the growing season. It was always believed that NT might have a disadvantage in nutrient availability and the need for additional N and P applications compared to conventional tillage systems. However, these findings showed the limited effect of increased N or P application has on increasing the utilization or recovery of these two nutrients by corn grown with all tillage systems. Further more, the most dominant or significant two-way interaction effect on plant N and P uptake or recovery was N rate x year rather than tillage x N rate or tillage x year interactions. Another interesting observation from these results is the similarity of nutrient value of both N sources and corn response to these two N sources across all tillage systems.

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